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PHYSICS OF FREE-ELECTRON-LASER APPLICATIONS

Physics of Free-Electron-Laser Applications in the Visible and Infrared

Physics of Free-Electron-Laser Applications in the Vacuum Ultraviolet–Extreme Ultraviolet

Physics of Free-Electron-Laser Applications in the Visible and Infrared

INTRODUCTION

It is now eighteen years since John Madey published a paper pointing out that a high-brightness relativistic electron beam traversing a spatially periodic magnetic field could stimulate the emission of photons over a broad range of wavelengths, indeed, from the far infrared to the ultraviolet. In a way, the free-electron laser was the ultimate homage paid by the laser, viewed as an optical device, to its antecedents in radar and electron-beam science and technology dating back into the 1940's.

In the intervening years, successful infrared and visible free-electron-laser (FEL) experiments, for example, at Stanford, Orsay, Santa Barbara, and Los Alamos, have shown significant promise for applications based on the unique optical characteristics of the FEL. A variety of accelerators can provide the high-brightness electron beams necessary for the FEL: room-temperature pulsed linear accelerators, superconducting accelerators, storage rings, and Van de Graaff generators have all been successfully used so far for this purpose. The existence of this variegated collection of pumps for the stimulated emission generated in the FEL implies a correspondingly broad range of temporal pulse shapes, interpulse spacings, pulse-repetition frequencies, output powers, and spectral ranges for users.

With the increasing maturity of the free-electron laser comes a new phase of scientific opportunity for those who are primarily laser users rather than laser physicists. During the past two years, FEL users' facilities at Stanford University and the University of California at Santa Barbara began to provide significant quantities of time to photon users, particularly in surface and materials science and biomedical studies. In the coming year, new FEL users' facilities devoted to biomedical and materials research as well as to FEL development will begin to operate at Vanderbilt and Duke; plans for additional facilities of this type are already far advanced.

Free-electron lasers now support significant experimental activities in a wide range of scientific and technological applications, including biomedical research. The spectrum of wavelengths now demonstrated in FEL's ranges from 0.25 to 800 μm, the region that includes atomic and molecular transitions as well as many elementary excitations in solids. While at least some parts of this spectral region can be covered by conventional lasers, the FEL has at least two major benefits compared with conventional lasers:

- The variety of FEL accelerator types offers the potential for decoupling the laser temporal-pulse structure and power output from the constraints of discharge or laser-pumping schemes and
- Beyond a wavelength of approximately 10 μm, the FEL has significantly greater tunability and higher power than any currently available lasers.

In addition, the fact that the interpulse spacing can be set much shorter than that available from mode-locked pulse trains (the Mark III FEL at Stanford and slated for installation at Vanderbilt, for example, has a rf accelerator frequency of 2.865 GHz, so that its pulses are 330 psec apart) makes it possible to carry out experiments in which the laser pulses follow one another on a time scale comparable with many relaxation times of physical, chemical, and biological interest.

In this special issue of *Journal of the Optical Society of America B*, we have collected a round dozen papers describing the physics of FEL applications in the visible and infrared. First, the companion papers on two-color FEL technology and applications suggest new opportunites in fundamental science that can be attained with the unique technology of the free-electron laser. In the near infrared, additional condensed-matter studies and surface science—particularly vibrational spectroscopy—have become possible with existing free-electron lasers. The gas-loaded free-electron laser can shift infrared FEL output into the visible, where work done with existing tabletop lasers can suggest ways in which the FEL, with its unique temporal pulse characteristics, might enhance our understanding of laser-induced processes both in materials science and in biomedical research. Finally, the far-infrared region was pinpointed early on as a place where exciting studies could be carried out in condensed-matter physics and biological physics. The papers submitted for this issue covering both recent research applications and new possibilities for direct excitation of far-infrared vibrational modes in solids suggest that this promise of the FEL is already being realized.

However, as with any new photon source, much of the challenge in developing new science will revolve around "thinking the unthinkable," or at least thinking the heretofore unthought. Thus the material ranges from reports of experimental results to inform speculations on possible future directions in FEL applications based on the unique properties of the FEL. Even though the *Journal of the Optical Society of America B* is an archival journal with a retrospective point of view, we hope that the speculation will stimulate as yet unthought, forward-looking applications of the FEL in the larger optical-science community.

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Physics of Free-Electron-Laser Applications in the Visible and Infrared